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EXPERIMENTS ON DERMAL SENSATIONS.[1]

BY HAROLD GRIFFING.

The Relation between the Intensity of the Stimulus and its Estimated Intensity.

Two stimuli differing greatly in intensity were successively applied to the hand of the observer, and he was required to judge how much greater one was than the other. The pressure was given by weights placed in the pan of a balance, and was transmitted to the hand by a wooden rod attached to the pan. The stimuli were 2, 10, 50, 250, 1250, and 1800 grams. The area of stimulation was that of a circle 4 mm. in diameter. The experiments made on four observers showed that on the average 10 g. was considered about twice as heavy as 2 g.; 50 g. twice as heavy as 10 g.; 250 g. three times as heavy as 50 g.; 1250 g. five times as heavy as 250 g.; and 1800 g. three times as heavy as 1250 g. It thus appears that for low and moderate intensities the estimate of intensity increases much more slowly than the objective intensity; but as the stimulus approaches the pain threshold, the reverse appears to be the case. Individuals differ, however, in their underestimation of low intensities, and also, but to a greater degree, in their overestimation of high intensities.

The Discrimination of Weights of Different Intensities.

Cylindrical boxes filled with shot served as stimuli. The method used was that of right and wrong cases; that is, the stimuli were placed successively upon the hand, and the ob-

[1] A full account and discussion of these experiments will be found in the writer's dissertation, *On Sensations from Pressure and Impact.* Supplement Monograph (No. 1) to this REVIEW.

server was asked to decide which was heavier. The accuracy of discrimination is measured by the probable error, or that increment which the observer perceives correctly 75% of the time.[1] Thus the greater the probable error the less the accuracy of discrimination. The stimuli varied from 100 to 3200 g., no more than four intensities being used for any one observer. The results of 9040 experiments made on 5 observers showed that the probable error for pressure stimuli tends to increase in proportion to the intensity of the stimulus within the approximate limits 300–3000 g. For low intensities the probable error increases much more slowly than the stimulus. For 5–7 g. the probable error for a good observer was $\frac{2}{5}$ of the stimulus. For high intensities also there seems to be a similar tendency, but it is not so marked. As illustrative of our results, we give the probable errors in grams for McW.: for 100 g., 19; for 500 g., 36; for 1500 g., 112; for 3200 g., 193. The average value of the probable error for all stimuli (100 g. and above) and all observers was approximately $\frac{1}{9}$ of the stimulus. That is we can, on the average, judge correctly whether one stimulus is heavier or lighter than another 75% of the time when the stimuli are in the ratio 9 : 10.

In these experiments the constant error, or tendency to overestimate the second stimulus, was found to be for some persons very great, running as high as $\frac{1}{3}$ of the stimulus. The constant error is more variable than the probable error; the expression 'constant error' is thus quite misleading. The constant error seems to be greater for observers having a large probable error. A great constant error for pressure is not necessarily accompanied by a similar overestimation for lifted weights.

The degree of confidence was studied by having the observers say *a*, *b*, *c* and *d*, according as they were certain, quite confident, less confident, or doubtful. Individuals differ greatly in their confidence, the percentage of wrong judgments of which observers were confident varying from 2% to 33%. The probability of correctness when confident

[1] This quantity has been considered to be equivalent to the least noticeable difference. It is doubtful, however, if such a relation can be justified.

was for most observers about .8 to .9. There appears to be no relation between these quantities and the accuracy of discrimination. The percentage of correct guesses varied from 52% to 70%, the average being 59%.

The Place of Stimulation.

The accuracy of discrimination for weights of 100 g. or more is not for two observers appreciably different for the palm of the hand, the back of the hand, and the volar surface of the third phalanx of the index finger. For 5–7 g. it was found at first to be much less for the back of the hand and wrist than for the index finger of one observer, but to increase greatly by practice. Stimuli of low intensity, 5 and 100 g., when placed on the forearm, tended to be judged lighter than when placed on the finger. This result was obtained by placing a weight first on the finger and then on the arm, increments being added until the weights seemed equal.

The writer tested the sensitiveness to pain at different parts of the body by the algometer.[1] It was found that the sensitiveness is greatest where the skin is thin and not separated from the bone by other tissues. Among the most sensitive parts are the upper regions of the head, whereas the palm of the hand, the thigh and the heel are among the least sensitive parts.

Sensations from Impact.

The tactile threshold for pressure stimuli without movement was found by observing the angular elevation of a bristle which was attached at one end to a wooden handle, and at the other could transmit pressure to the skin. In this way it was found that .4 g. is about as easily perceived when movement is thus excluded, as is .01 g., when the stimulus is placed carefully upon the hand. The difference in the results is due to the sensory effect of movement.

By dropping weights upon the hand, the heights were found at which different weights caused pain. The weights were 25, 100, 200 and 300 g. The area of stimulation was

[1] An instrument by which pressure could be exerted up to 15 k.

constant, a circle about 1 cm. in diameter. The results of 60 measurements showed that the product of the mass and height pain-thresholds is fairly constant. As the height through which a body falls is proportional to the square of the velocity, the pain threshold and therefore the intensity of pain, depend as much upon the square of the velocity as upon the mass of a striking object.

By the method of right and wrong cases we studied the accuracy of discrimination for impact stimuli. The results of 800 experiments showed that a weight of 50 g., falling through 17.5 cm., is judged about as well as 1000 g. without movement. The average probable error for pressure only was $\frac{1}{11}$ of the stimulus for S. F., and $\frac{1}{14}$ for L. F. For impact the corresponding values were $\frac{1}{10}$ and $\frac{1}{12}$.

In 900 experiments, carried on in the same way, the weight was kept constant and the observer required to estimate differences in the intensity of the blow due to differences in height and therefore velocity. The results were compared with those based upon the same number of experiments on the same observers, in which the height was constant and the weight variable. We found that, on the whole, differences in weight are judged less accurately than differences in velocity, but more accurately than differences in the square of the velocity. But great individual variations occur.

Experiments were also made on the intensive effect of the weight as compared to that of the velocity. A 100 g. weight having fallen upon the hand from a height of 5 cm., the height was found at which 25 g. would cause a sensation of the same intensity. Here also observers differed greatly. The average height for 5 observers was 38 cm., the maximum being 58, the minimum 20 cm. Hence the mass has in general greater intensive effect than the height or the square of the velocity. Otherwise the average height found would be about 20 cm. On the other hand, the mass has less effect than the velocity or square root of the height.

The Area of Stimulation.

In the experiments on Weber's law two areas were used, 8 sq. cm. and .12 sq. cm. approximately. It was found that

on the whole this difference of area did not affect the accuracy of discrimination for weights. Individual variations, however, were very marked.

If stimuli of the same weight, but different areas, be placed successively upon the hand, the stimulus applied on the smaller area will be overestimated. By applying the method of right and wrong cases we measured this overestimation. The results of 400 experiments on one observer gave an overestimation of $\frac{1}{3}$ of the stimulus at 200 g. Experiments by a different application of the method of right and wrong cases on 5 observers gave about the same result, except that one observer showed a tendency to underestimate, rather than overestimate, the stimulus applied to the smaller area. By a third method, however, we found a decided overestimation for only 2 out of 5 observers. From these experiments on 10 observers, we conclude that this tendency is by no means universal.

The effect of alterations in the intensity of pressure on the accuracy of discrimination of areas was investigated by the method of right and wrong cases, differences in area being judged instead of differences in intensity. The standard areas used were 1 and 8 sq. cm. and the intensities 200 and 800 grams. The results of 1900 experiments on 3 observers showed that the accuracy of discrimination for areas was, on the average, about $\frac{1}{3}$ greater for 200 g. than for 800 g.

By placing thin circular cards upon the hand and applying pressure upon these, we studied the effect of variations in the area on the so-called tactile threshold. The areas were approximately 1 mm., 10 mm. and 90 mm. The averages of the corresponding threshold values, based upon 60 experiments, were for F., .2 g., .9 g. and 1.9 g.; and for the writer, .5 g., 1.4 g. and 1.6 g. Thus the smaller the area the greater the probability that stimuli of low intensity will be perceived.

In a similar manner the relation of the pain threshold to the area of stimulation was investigated. The average values of the pain threshold, based upon 80 experiments on two observers, were: for 10 mm., 1.4 kilog.; for 30 mm.,

2.8 kilog.; for 90 mm., 4.4 kilog.; and for 270 mm., 6.6 kilog. Thus the pain threshold increases with the area; but, like the tactile threshold, much more slowly than in direct proportion.

The Time of Stimulation.

The sensory effect of pressure stimuli of low intensity was found to depend upon the rate at which the pressure was increased. The instrument used was that referred to in the experiments already described on the tactile threshold. By this pressure was exerted upon the palm of the observer's hand up to .4 g., at different rates of increase. These rates were approximately .05 g., .3 g. and 2 g. per second. The corresponding percentages of times the stimulus was perceived in 300 experiments on 2 observers were 6%, 32%, and 82%. Thus the greater the rate of increase the greater the probability of perception.

The time in which dermal stimuli of different intensities cause pain was found in the following manner. Different weights were placed in a balance pan so as to press upon the palm of the hand, and the time was noted which elapsed before the appearance of pain. The pressure was communicated from the pan to the hand by a wooden rod fastened to the pan. The diameter of the base was 1.5 mm. The averages in seconds, based upon 80 experiments on 2 observers, are as follows: for 100 g., 230 sec.; for 200 g., 35 sec.; for 300 g., 10 sec.; for 500 g., 4.5 sec. It is evident, therefore, that the time as well as the area and intensity of stimulation determine the sensory effect. There is, however, an intensive limit, below which pressure stimuli never become painful. This is probably from 25 to 50 g. for the area used.

THE AFTER-IMAGE THRESHOLD.

BY SHEPHERD IVORY FRANZ.

Ever since Aristotle described in his De Somniis[1] the appearance of an after-image, the phenomena have attracted

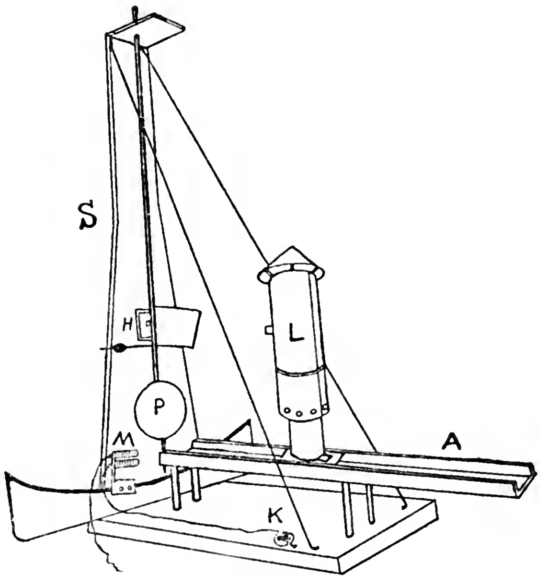
[1] This seems not to be generally known by German writers. Aubert and Helmholtz both credit Peiresc as being the first to mention after-images.

attention. St. Augustine mentions them, and in modern times such prominent men as Buffon, Goethe and Newton have described their appearance. But very little was accomplished beyond the making of theories until this century, when Plateau, Seguin, Fechner and others studied the color changes. Up to the present time practically nothing has been accomplished in the way of exact measurement.

The present paper gives the results of an attempt to measure the smallest amount of light which will produce an after-image. For this purpose three physical units had to be considered—the intensity of the light, its area, and the time of stimulation. The apparatus used was planned and formerly used by Prof. Cattell, but was adapted by the writer. It is represented in the accompanying cut.

Gift Dr Franz 1928

FIGURE 1.



S is an upright iron screen pierced by a hole (H) through which the light from the hooded lamp (L) may pass to the observer on the other side of the screen. P is a seconds pendulum. To this is attached a piece of sheet iron which covers the hole when the pendulum is held up by the electro-magnet (M). The key (K) which makes and breaks the current to the magnet (M) is managed by the experimenter, and

the pendulum is held up or let swing at his pleasure. By breaking and making the current the pendulum swings, permits the light to be seen by the observer for exactly one second, and is caught up again by the magnet. The lamp is moved along the arm (A), increasing or decreasing the intensity of the light. The opening (H) was covered with ground glass. $\frac{1}{100}$ candle power was found a convenient intensity, this being increased by moving the lamp nearer the observer, and decreased by moving it away from the observer. The lamp was used at the distances $\frac{1}{4}$, $\frac{1}{2}$, 1, 2 and 4 meters, and so far as the intensity decreases inversely as the square of the distance, the respective intensities would be $\frac{4}{25}$, $\frac{1}{25}$, $\frac{1}{100}$, $\frac{1}{400}$ and $\frac{1}{1600}$ candle power. The absorbing power of the ground glass was found to be 50%, whence the intensities were decreased by half—making the series—$\frac{2}{25}$, $\frac{1}{50}$, $\frac{1}{200}$, $\frac{1}{800}$, $\frac{1}{3200}$, c. p. In the experiments on intensity, the time of exposure (one second) and the area (64 sq. mm.) were kept constant. For the experiments on area, the lamp was placed at a distance of $\frac{1}{4}$ m., thus making the intensity $\frac{2}{25}$ c. p., the time (one second) being the other constant. The area was changed by using different pieces of ground glass on which black paper blocked off all but the small area required. The areas used were 64, 16, 4, 1, $\frac{1}{4}$, $\frac{1}{16}$ sq. mm. When time was the changeable unit, the area (64 sq. mm.) and the intensity ($\frac{2}{25}$ c. p.) were the constants. The series consisted of four times, $\frac{1}{000}$, $\frac{1}{100}$, $\frac{1}{10}$ and 1 second. The shorter times were obtained by means of drop screens, made of pasteboard and weighted. As they did not fall in grooves there was no appreciable friction, and hence the real time practically corresponded with the theoretical time. The screen was on the side of the apparatus near the observer, and therefore is not shown in the cut. The time one second was given by the pendulum. As will be noticed, there was a common unit in the three series, *i. e.*, when the experiments were made with 1 sec., 64 sq. mm. and $\frac{2}{25}$ c. p.

The experiments were conducted in a dark room, and all observations were made with the eyes open, so as not to disturb the after-image. A cloth curtain was hung across the room, shutting off from the observer everything but the

small opening in the screen. The observer's eyes were 30 cm. from the opening, his head being steadied by a support. Before any experiments were made a rest of ten minutes was taken to allow the observer's eyes to become accustomed to the darkness; between the disappearance of one after-image and the next stimulus there was a rest of thirty seconds. When the thirty seconds had elapsed a signal was given, five seconds were allowed for preparation, and the stimulus was produced.

Very few difficulties presented themselves, and of these the only one not overcome was the lack of a fixation point, as any fixation point was apt to produce a disturbing after-image. By practice, however, the observer learned to look in a certain way for the stimulus, and in the case of the writer not over five per cent. of the time were the eyes consciously focussed after any part of the light was seen. The kerosene lamp used was trimmed at the beginning of the experiments. By photometric determinations always made before a sitting and generally during and after the sitting, it was found that the light varied very little or not at all.

Four observers were tested, C., McW. and S. respectively with time, area and intensity. All were advanced students in psychology, and S. had had previous experience with after-images. F., the writer, was the fourth observer, the three series being made upon him.

The results of nearly 3,000 experiments are given in the following tables. In the first line the percentage of times an after-image was seen is given, and in the second line the average variation of the sets of ten trials; 100 experiments of each sort were made, excepting in those cases in which a different number is given in parenthesis.

Some preliminary experiments on area made on the writer bear out in general the results in the corresponding series. These experiments were made with an intensity of $\frac{1}{20}$ c. p., so that they could not be combined with the others. The other constant was an exposure of one second. The same areas were used except that the $\frac{1}{16}$ sq. mm. was omitted. Seventy experiments were made on each area. The results, with the average variations, are shown in the accompanying table.

INTENSITY.

Intensity in candle power.		$\frac{2}{25}$	$\frac{1}{50}$	$\frac{1}{200}$	$\frac{1}{800}$	$\frac{1}{3200}$
S.	Percentage,	100	94	48	17	2
	Variation,	— (80)	7	25 (110)	20.8 (110)	3.6
F.	Per cent.,	100	96	44	15.5	1
	Var.,	—	5.4	19.5 (130)	13.5 (130)	1.8

AREA.

Area in square mm.		64	16	4	1	$\frac{1}{4}$	$\frac{1}{16}$
McW.	Per cent.,	100	90	72	52	27	20
	Var.,	— (50)	7.5 (80)	14.8	12.4	9.2	6
F.	Per cent.,	100	96	88	57	31	8
	Var.,	—	4.8	8.8	13	15.4	8

TIME.

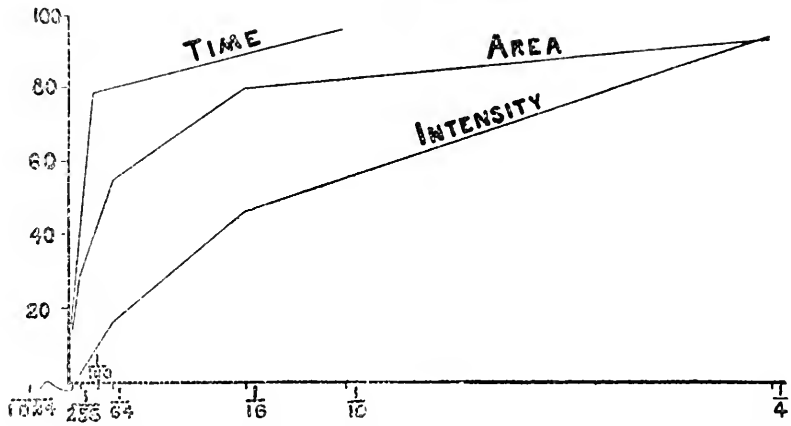
Time in seconds.		1	$\frac{1}{10}$	$\frac{1}{100}$	$\frac{1}{1000}$
C.	Per cent.,	97	95	75	12
	Var.,	3.5 (70)	7	17	10.8
F.	Per cent.,	100	97	82.5	19
	Var.,	—	4.2	8.3 (120)	7.4

AREA.

Area in sq. mm.		64	16	4	1	$\frac{1}{4}$
F.	Per cent.,	96	89	67	41	19
	Var.,	5	10	14.7	10	9.9

The results of the first three tables are represented graphically by the accompanying curves.

FIGURE 2.



The abscissa denotes respectively divisions of time, area and intensity, the ordinate the percentage of times an after-image appeared. The curves are not carried out to represent the greatest intensity, the greatest area and the greatest time. Each curve is the average of the two observers in that series, the close agreement of the observers making this method permissible. The figures on the abscissa represent the proportion of that stimulus to the greatest stimulus, taking respectively time, area and intensity as the variables.

If we regard the threshold as that intensity, time or area, which produces an after-image 75% of the number of stimuli, we conclude

(1). That with an exposure of one second and an intensity of $\frac{2}{25}$ c. p., the threshold is 4 sq. mm.

(2). That with the area 64 sq. mm. and the intensity $\frac{2}{25}$ c. p., the threshold is $\frac{1}{100}$ second.

(3). That with the area 64 sq. mm. and the time of exposure one second, the threshold is $\frac{1}{100}$ candle power (approximately), or between $\frac{1}{50}$ and $\frac{1}{250}$ c. p.

If we substitute in our definition 25%, or 50%, or 90%, for the 75%, we but change the figures to suit the case.

It is worth noting that of the 1,500 cases when after-images were seen, but five were negative, a proof of the theory that the negative after-image is due to exhaustion of the eyes, the low intensities, the small areas and the short times not being sufficient to tire or exhaust the eyes. These five negative images were all seen toward the close of a sitting, when the eyes had been used for forty or fifty experiments, and all were with the greatest intensity, the longest time and the largest area.

With the results obtained we are able to make a further comparison—a correlation of our physical units in terms of the production of after-images—a purely psychological problem. How much time equals how much intensity or area? A glance at the curves and percentages shows that equal increments in area, intensity and time do not give equal results. If we represent our constants by the letters c, c′ and c″ respectively for intensity, time and area, and let i, t and a represent respectively $\frac{1}{800}$ c. p., $\frac{1}{1000}$ sec. and $\frac{1}{16}$ sq. mm., from the table of percentages we get the following approximate equations.—

$$i\,c = t\,c' = a\,c''$$
$$(2\,i\,c) = (1.7\,t\,c') = (4\,a\,c'')$$
$$4\,i\,c = 3.2\,t\,c' = 16\,a\,c''$$
$$8\,i\,c = 10\,t\,c' = 64\,a\,c''$$
$$16\,i\,c = 100\,t\,c' = 256\,a\,c''$$

The 8 i c and the 3.2 t c′ represent $\frac{1}{100}$ c. p. and $\frac{3.2}{1000}$ sec. (approximately). These figures and the second equation in brackets are supplied from the curves. The relations, then, may be stated as follows: "Squaring the time equals doubling the intensity or quadrupling the area," and vice versa, "reducing the area to one-fourth equals halving the intensity and taking the square root of the time." Whether this be a chance relation or a general one throughout the phenomena of after-images cannot be dogmatically stated now. The writer has in view the further study of this problem.